# Flight-Control Augmentation for Aft Center-of-Gravity Launch Vehicles

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The space shuttle was only the first step in achieving routine access to space. Recently, MSFC has been studying a whole spectrum of new launch vehicles for space transportation. Some of these could transport components of the space station to orbit, and some could take us to Mars and beyond to expand our frontiers of knowledge.

In all our future launch vehicle designs, decreasing the structural weight will always be of great concern. This is tantamount to increased payload capability, which, in turn, means reduced cost per pound to orbit. One very significant increase in payload capability has been defined: a sizable weight savings can be realized by a rearrangement of the internal propellant tanks. Studies have been conducted both at MSFC and at Martin Marietta Corporation (maker of the space shuttle external tank) which show that a very substantial weight can be saved by inverting the relative positions of the liquid-hydrogen and liquid-oxygen propellant tanks.

As the vehicle sits on the launch pad in the conventional configuration, the heavier liquid-oxygen tank is located on top of the lighter hydrogen one, requiring a heavy structural member between the two tanks to prevent the lighter tank from being crushed. The configuration also requires large, long, and even drag-producing liquid-oxygen feedlines running the length of the vehicle on the exterior fuselage. If the relative position of the propellant tanks is inverted, both the heavy structural separation member and the long feedlines could be deleted.

While the structures community at MSFC was elated with this finding, the liquid-oxygen tank aft configuration gave the vehicle an aft center-of-gravity location that surfaced controllability concerns. In the conventional configuration, the launch vehicle is controlled in the ascent trajectory by the gimballing of its rocket engines. Studies have been conducted at MSFC to show that the resulting aft center-of-gravity-configured vehicle would not be adequately controllable with the engine gimballing alone.

Today, more aft center-of-gravity launch vehicles are appearing. In addition to an aft center of gravity being caused by an internal rearrangement of propellant tanks, aft center-of-gravity vehicles are also appearing due to heavier rocket engines and larger numbers of aft engines. Therefore, in the new spectrum of launch vehicles being considered, the controllability of the aft center-of-gravity-configured vehicle must be assessed. When the available control authority has been determined to be inadequate or marginal, some means of flight-control augmentation is required.

This research effort has proposed, designed, and wind tunnel-tested a novel solution to provide the required flight-control augmentation for an aft center-of-gravity-configured vehicle, when needed most in the ascent trajectory during maximum dynamic pressure. The vehicle used in the research is one that has recently been studied at MSFC. The liquid-hydrogen and liquid-oxygen propellant tanks in the external tank have been interchanged, giving the vehicle an aft center of gravity. Research indicates that engine gimballing alone does not offer adequate control; the required flight-control augmentation is provided by aerodynamic flight-control augmentors. This solution not only solves the original problem of augmenting the control of the aft center-of-gravity vehicle, but also can be used in the marginal control configuration to enhance controllability as load alleviators to reduce engine-gimballing requirements, to provide engine actuator failure protection, and to enhance crew safety and vehicle reliability by providing more control in engine-out events.

These devices can reduce the wind restrictions. Conventionally, the launch vehicle loads during ascent are alleviated by turning the vehicle into the wind, thereby reducing the vehicle's angle of attack. Thus, load relief is accomplished at the expense of trajectory deviation. Load-relief control is most necessary when the vehicle experiences maximum dynamic pressure and the aerodynamic loads are greatest, which happens to be when the flight-control augmentors would provide the most significant assistance. The added control capability through the use of these surfaces allows greater tolerance of wind magnitudes and a minimization of bending moments on the vehicle, both during ascent and during launch. For prelaunch, the unfueled vehicle on the pad is assumed to withstand peak loads of 75 knots and, fueled at liftoff, peak winds of 50 knots. The environmental disturbances are multiplied by 1.5 to account for Von Karman vortex shedding effects. Wind profiles show greatest steady wind speeds occurring between 20,000 and 60,000 feet, with a gust overshoot of up to 50 percent. The more the engines are required to gimbal, the more engineering design and cost are involved to have the propellant ducts move with the gimbal action while maintaining a full flow of fuel. The extension, compression, and torsion of the propellant ducts become limiting factors of engine gimballing. Thus, the designed flight-control surfaces of this research provide the required control augmentation, as well as a plethora of additional significant benefits.

Through this effort, current and past uses of launch vehicle aerodynamic surfaces have been reviewed. NASA has a rich national heritage of launch vehicles that have used aerodynamic surfaces, both to provide flight stability and to provide flight control. The Saturn V took humankind to the Moon wearing 300 square feet of aerodynamic surfaces to provide flight stability. Since landing on the Moon, the wealth of smart materials and advanced composites that have been developed allow for the design of very lightweight, strong, and innovative launch vehicle flight-control augmentors. Today, a myriad of launch vehicles have been actively launched from over 15 geographic sites. Aerodynamic surfaces currently being used by other nations on launch vehicles have been reviewed.

The flight-control requirements analyses of this research have been conducted to determine the amount of flight-control augmentation required. Based on these determined control requirements, the above reviews, the generated vehicle mass properties, and ascent trajectory data, candidate flight-control augmentors have been designed and fabricated, along with experimental launch vehicle test articles. A static wind tunnel test program and a dynamic wind tunnel test program have been conducted at MSFC for these candidate flight-control augmentors and the host experimental aft center-of-gravity launch vehicle. The wind tunnel test programs have produced data for the static stability and dynamic stability derivatives. The wind tunnel test data have been reduced and utilized to conduct the vehicle static stability analyses and dynamic stability analyses. Results have been compared to DATCOM-generated analytic data.

The best candidate designs demonstrate the augmented control authority achievable with the use of the flight-control augmentors. Figure 73 shows the flow chart of this conducted research effort, while figure 74 illustrates the fabricated aft flight-control augmentors tested on the experimental launch vehicle in MSFC’s wind tunnel. Figure 75 depicts the fabricated forward flight-control augmentors tested on the launch vehicle. Figure 76 offers the experimental wind tunnel test article with aft devices attached, and figure 77 shows the experimental vehicle test article with forward and aft devices attached.

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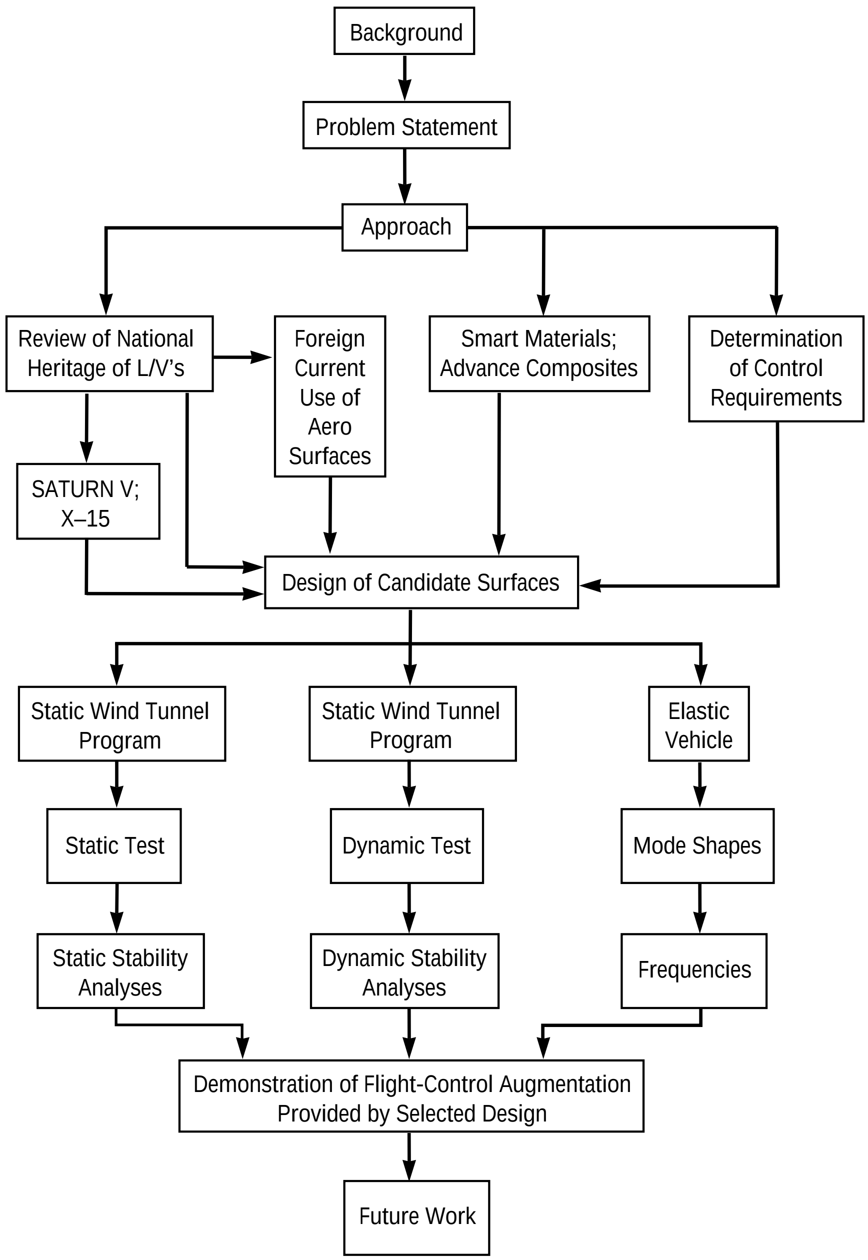


Figure 73.—Flow chart of conducted research.

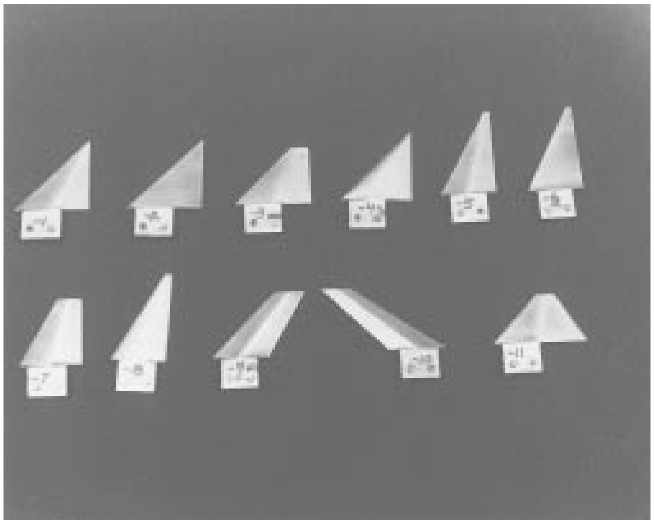

Figure 74.—Fabricated aft launch vehicle flight-control augmentation devices.

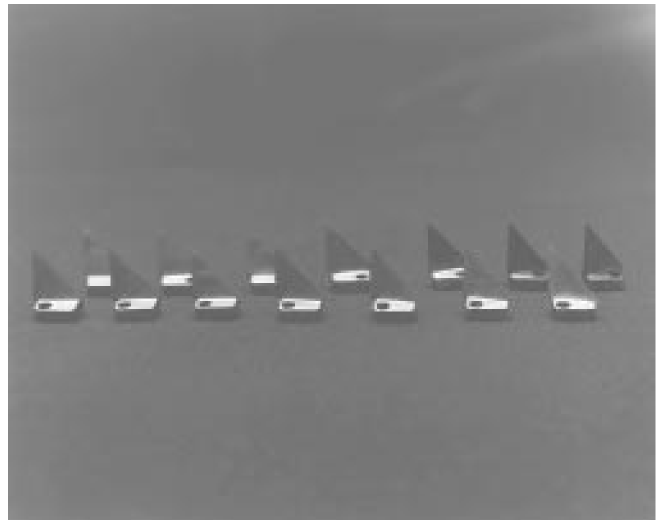

Figure 75.—Fabricated forward launch vehicle flight-control augmentation devices.

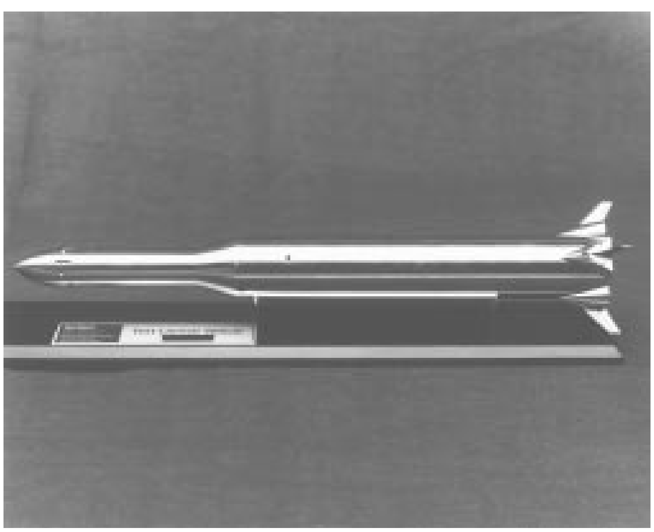

Figure 76.—Fabricated launch vehicle wind tunnel test article with flight-control augmentation devices attached aft.

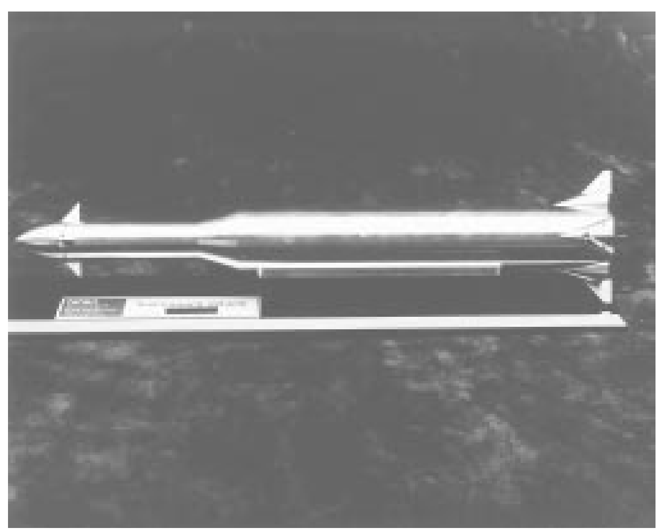

Figure 77.—Fabricated launch vehicle wind tunnel test article with flight-control augmentation devices attached aft and forward.